10/589333
SUBSTITUTE SPECIFICATION
IAP20 Rec'd PCT/PTO 14 AUG 2006

BRAYTON CYCLE DEVICE AND EXHAUST HEAT ENERGY RECOVERY DEVICE FOR INTERNAL COMBUSTION ENGINE

INCORPORATION BY REFERENCE

This is a 371 national phase application of PCT/JP2005/001299 filed 25 January 2005, claiming priority to Japanese Patent Application No. 2004-044967 filed 20 February 2004, the contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to an apparatus realizing a Brayton cycle and an apparatus for recovering exhaust heat energy of an internal combustion engine using a Brayton cycle.

BACKGROUND OF THE INVENTION

To improve the fuel efficiency of an internal combustion engine, an apparatus for recovering exhaust energy that is discharged from the engine after fuel is burned has been used. For example, a Rankine cycle apparatus is mounted on a vehicle together with an internal combustion engine. A vaporizer arranged in the Rankine cycle apparatus generates high-temperature high-pressure vapor by heating water, which is contained in the apparatus, using exhaust heat energy. An expander generates power using the vapor (refer for example to Japanese Laid-Open Patent Publication No. 2003-120281).

As other techniques for recovering exhaust energy, combining an engine that uses heat, such as a Stirling engine, with an internal combustion engine (refer for example to Japanese Laid-Open Patent Publication No. 2001-

99003) or directly drawing exhaust into a scroll expander (refer for example to Japanese Laid-Open Patent Publication No. 2003-138933) have been proposed.

However, the apparatus described in Japanese Laid-Open Patent Publication No. 2003-120281 needs a vaporizer, an expander, a condenser, and a pump, which functions with a working fluid. This inevitably increases the volume and the weight of the apparatus. Thus, even if the apparatus efficiently recovers the exhaust heat energy, the drive energy of the apparatus or the weight of the vehicle may become excessive. In this case, the improvement in engine fuel efficiency would become subtle. The same problem occurs to the technique using a heat engine, such as a Stirling engine, which is described in Japanese Laid-Open Patent Publication No. 2001-99003.

Further, Japanese Laid-Open Patent Publication No. 2003-138933 describes a technique for drawing exhaust into a scroll expander. This inevitably increases the exhaust back pressure of the internal combustion engine and lowers the engine output. In this case, there may be no improvement in the engine fuel efficiency as a whole.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an exhaust heat energy recovery apparatus for an internal combustion engine for recovering the exhaust heat energy efficiently without increasing the exhaust back pressure of the internal combustion engine. It is another object to provide a Brayton cycle apparatus applicable to such an exhaust heat energy recovery apparatus.

The means for achieving the above objects and its

advantages will now be described.

The present invention provides a Brayton cycle apparatus. The Brayton cycle apparatus includes a scroll compressor, a scroll expander that operates in cooperation with an orbiting action of the scroll compressor, and a heating device for heating a compressed working fluid that is fed from the scroll compressor to the scroll expander.

Unlike a gas turbine Brayton cycle apparatus of the prior art, this Brayton cycle apparatus uses the scroll compressor and the scroll expander and simplifies its structure. The simplified structure downsizes the apparatus. In the Brayton cycle apparatus, the working fluid is moved, compressed, and expanded inside the compressor and the expander in partitioned and sealed spaces. Thus, the efficiency of conversion from heat energy to kinetic energy is high.

Further, the heating device heats the working fluid by heat transfer to drive the Brayton cycle apparatus of the present invention. Thus, the pressure of the energy source itself causes no problem, and the back pressure of the energy source including the exhaust is unaffected.

In this manner, the Brayton cycle apparatus of the present invention efficiently converts heat energy to kinetic energy without increasing the back pressure of the energy source. Thus, even when the Brayton cycle apparatus of the present invention is applied to, for example, an internal combustion engine, the apparatus recovers the exhaust heat energy efficiently without increasing the exhaust back pressure.

Preferably, an orbital compression scroll of the

scroll compressor and an orbital expansion scroll of the scroll expander are arranged at opposite sides of an orbital partitioning wall. The orbital compression scroll of the orbital partitioning wall comes in contact with a compressor case in which a fixed compression scroll is formed in a slidable manner or faces the compressor case with a narrow space between them. As a result, the orbital compression scroll is combined with the fixed compression scroll to form the scroll compressor. The orbital expansion scroll on the orbital partitioning wall comes in contact with an expander case in which a fixed expansion scroll is formed in a slidable manner or faces the expander case with a narrow space between them. As a result, the orbital expansion scroll is combined with the fixed expansion scroll to form the scroll expander.

The scroll compressor and the scroll expander are formed in this manner so that the Brayton cycle apparatus is further simplified and downsized.

Preferably, the scroll compressor releases heat transferred from the scroll expander to the orbital partitioning wall into the atmosphere via the compressor case.

The scroll compressor comes in contact with the scroll expander through the orbital partitioning wall. Thus, the compressor case at a low-temperature side receives heat of the orbital partitioning wall transferred from the scroll expander at a high-temperature side and releases the heat into the atmosphere. The heat releasing effect of the compressor case prevents the orbital partitioning wall from being heated to a high temperature. As a result, the orbital partitioning wall is prevented from being deformed by heat, and the dimensional accuracy

of the orbital partitioning wall is maintained. This prevents the working fluid from leaking, and prevents the friction coefficient during orbiting of the orbital partitioning wall from becoming large. This maintains high energy conversion efficiency.

As a result, the orbital partitioning wall or the compressor case in particular may be made of a lightweight material with a low heat resistance. This contributes to further decreasing the weight of the apparatus.

Preferably, the scroll expander guides the working fluid introduced into a heat absorption chamber defined in the expander case before the introduced working fluid expands so that the working fluid that is being expanded is heated by a wall of the heat absorption chamber.

The scroll expander with this structure enables the working fluid that is being expanded in the scroll expander to be heated by the heat of the working fluid prior to compression. This enables the Brayton cycle apparatus to convert heat energy to kinetic energy more efficiently without complicating the structure of the apparatus.

Preferably, the scroll compressor uses atmospheric gas as the working fluid and compresses the atmospheric gas, and the scroll expander releases the expanded working fluid into the atmosphere.

The atmospheric gas is used as the working fluid in this manner and eliminates the need for an apparatus for releasing heat of the working fluid. This further simplifies and downsizes the structure of the apparatus.

Preferably, the heating device is formed as a heat

exchanger for transferring external heat to the working fluid by heat exchange.

In this manner, the heating device is formed as a heat exchanger so that the apparatus is further simplified and downsized. Further, even when the Brayton cycle apparatus is used to collect exhaust heat energy of, for example, an internal combustion engine, the apparatus does not increase the exhaust back pressure.

The present invention further provides a Brayton cycle apparatus including a positive-displacement compressor, a scroll expander for performing orbiting action in cooperation with the compression action of the positive-displacement compressor, and a heating device for heating the compressed working fluid that is fed from the positive-displacement compressor to the scroll expander.

Unlike a conventional gas turbine Brayton cycle apparatus, the Brayton cycle apparatus uses the positive-displacement compressor and the scroll expander. Thus, this Brayton cycle apparatus has a simple structure. The simple structure downsizes the apparatus. Further, in the Brayton cycle apparatus, the working fluid is moved, compressed, and expanded inside the compressor and the expander in partitioned and sealed spaces. Thus, the efficiency of conversion from heat energy to kinetic energy of the Brayton cycle apparatus is high.

Further, the heating device heats the working fluid by heat transfer to drive the Brayton cycle apparatus of the present invention. Thus, the pressure of the energy source itself causes no problem, and the back pressure of the energy source including the exhaust is unaffected.

In this manner, the Brayton cycle apparatus of the present invention converts heat energy to kinetic energy without increasing the back pressure of the energy source. Thus, when the Brayton cycle apparatus of the present invention is applied to, for example, an internal combustion engine, the apparatus recovers the exhaust heat energy efficiently without increasing the exhaust back pressure.

Preferably, a wall surface of the expander in the Brayton cycle apparatus is kept warm.

The wall surface of the expander is kept warm in this manner so that heat energy is prevented from leaking from the expander. As a result, the expander converts heat energy to kinetic energy further efficiently.

The present invention further provides an exhaust heat energy recovery apparatus for an internal combustion engine. The energy recovery apparatus uses a Brayton cycle apparatus for heating a compressed working fluid that is fed from a compressor to an expander by heat transferred from a flow passage wall of an exhaust passage of the internal combustion engine. As a result, the heat energy recovery apparatus recovers the exhaust heat energy as kinetic energy.

In this manner, the exhaust heat energy recovery apparatus of the present invention uses the Brayton cycle apparatus to heat the working fluid by heat transfer to collect exhaust heat energy of the internal combustion engine. Thus, the exhaust heat energy recovery apparatus of the present invention recovers the exhaust heat energy efficiently without increasing the exhaust back pressure of the internal combustion engine.

Preferably, a heating device included in the Brayton cycle apparatus of the heat energy recovery apparatus is formed as a heat exchanger for transferring external heat to the working fluid by heat exchange. This heat exchanger is arranged to come in contact with the exhaust of the internal combustion engine.

This structure simplifies and downsizes the exhaust heat energy recovery apparatus and enables the exhaust heat energy recovery apparatus to be easily mounted on a vehicle etc. This exhaust heat energy recovery apparatus recovers the exhaust heat energy efficiently without increasing the exhaust back pressure of the internal combustion engine.

Preferably, the exhaust flow passage is formed as a double pipe having an inner passage and an outer passage. Heat exchange is performed between the exhaust flowing through one of the inner passage and the outer passage of the double pipe and the working fluid flowing through the other one of the passages.

In this manner, the exhaust flow passage is formed as a double pipe to enable such heat exchange so that the compressed working fluid is easily heated using the exhaust heat energy.

Thus, the simple and compact structure enables the exhaust heat energy to be recovered efficiently without increasing the exhaust back pressure of the internal combustion engine.

Preferably, the Brayton cycle apparatus includes a scroll compressor and a scroll expander that are arranged at opposite sides of an orbital partitioning wall. The

orbital partitioning wall and the compressor case are made of a high heat-conductive material, and the expander case is made of a heat-resistant material.

The compressor case made of a high heat-conductive material is at a low temperature side in the Brayton cycle apparatus. The orbital partitioning wall is also made of a high heat-conductive material. Thus, the compressor case of the Brayton cycle apparatus is cooled first. This eliminates the need for using a heat-resistant material for the orbital partitioning wall and the compressor case. The expander case that directly comes in contact with the high-temperature working fluid is made of a heat-resistant material so that the exhaust heat energy recovery apparatus of the internal combustion engine is formed.

Preferably, an aluminum alloy is used as the high heat-conductive material, and an iron alloy is used as the heat-resistant material.

In this manner, the use of an aluminum alloy as the high heat-conductive material contributes to further decreasing the weight of the exhaust heat energy recovery apparatus.

Preferably, a wall surface of the expander is kept warm.

In this manner, the use of the Brayton cycle apparatus in which the wall surface of the expander is kept warm enables heat energy to be converted to kinetic energy more efficiently, and enables the exhaust hest energy to be recovered efficiently.

The present invention further provides a Brayton

cycle apparatus including a scroll expander formed by combining an orbital expansion scroll with a fixed expansion scroll, a compressor for operating in cooperation with the orbiting action of the orbital expansion scroll to compress a working fluid, a compressed working fluid flow passage for supplying the working fluid from the compressor to the scroll expander, and a heat source for heating the working fluid in the scroll expander by heat transfer.

More specifically, the Brayton cycle apparatus is not limited to a structure in which the working fluid is heated by a compressed working fluid passage for supplying the working fluid from the compressor to the scroll expander and may have a structure for heating the working fluid in the scroll expander using heat transferred from the heat source.

In this case, heating the working fluid in the scroll expander using heat transferred from the heat source drives the Brayton cycle apparatus of the present invention. As a result, the pressure of the heat source itself causes no problem, the back pressure of the heat source is unaffected, and heat energy is efficiently converted to kinetic energy. As a result, even when the Brayton cycle apparatus of the present invention is applied to, for example, an internal combustion engine, the apparatus recovers the exhaust heat energy efficiently without increasing the exhaust back pressure.

Further, the working fluid is not heated by the compressed working fluid passage. This simplifies the structure of the compressed working fluid passage itself. This further enables the working fluid to be heated by heat transfer using the structure of the scroll expander so that the Brayton cycle apparatus is further simplified and

downsized.

Preferably, the compressor is a positive-displacement compressor.

When the positive-displacement compressor is used in this manner, the working fluid in the scroll expander is heated in the manner described above. As a result, even when the Brayton cycle apparatus of the present invention is applied to, for example, an internal combustion engine, the apparatus recovers the exhaust heat energy efficiently without increasing the exhaust back pressure.

The present invention further provides a Brayton cycle apparatus including an orbital partitioning wall having a first surface on which an orbital compression scroll is formed and a second surface on which an orbital expansion scroll is formed, a scroll compressor formed by combining the orbital compression scroll with a fixed compression scroll, a scroll expander formed by combining the orbital expansion scroll with a fixed expansion scroll, a compressed working fluid passage for supplying working fluid from the scroll compressor to the scroll expander, and a heat source for heating the working fluid in the scroll expander by heat transfer.

More specifically, the Brayton cycle apparatus is not be limited to the structure in which the working fluid is heated on the compressed working fluid passage for supplying the working fluid from the scroll compressor to the scroll expander and may have a structure for heating the working fluid in the scroll expander by heat transfer from the heat source.

Unlike a conventional gas turbine Brayton cycle

apparatus in the prior art, the Brayton cycle apparatus uses the scroll compressor and the scroll expander and simplifies the structure. The simplified structure downsizes the apparatus. In the Brayton cycle apparatus, the working fluid is moved, compressed, and expanded inside the compressor and the expander in partitioned spaces. Thus, the efficiency of conversion from heat energy to kinetic energy is high.

Further, heating the working fluid by heat transferred from the heat source drives the Brayton cycle apparatus of the present invention. As a result, the pressure of the heat source itself causes no problem, and the back pressure of the heat source is unaffected.

The Brayton cycle apparatus of the present invention converts heat energy to kinetic energy efficiently without increasing the back pressure of the heat source. As a result, even when the Brayton cycle apparatus is applied to, for example, an internal combustion engine, the apparatus recovers the exhaust heat energy efficiently without increasing the exhaust back pressure.

Further, the working fluid is not heated in the compressed working fluid passage. This simplifies the structure of the compressed working fluid passage itself and further enables the working fluid to be heated by heat transfer using the structure of the scroll expander so that the Brayton cycle apparatus is further simplified and downsized.

Preferably, the compressed working fluid passage is a through-hole formed in the orbital partitioning wall. The through-hole communicates an internal space of the case of the scroll compressor with an internal space of the case of

the scroll expander that is formed to sandwich the orbital partitioning wall together with the scroll compressor.

The through-hole of the orbital partitioning wall also functions as the compressed working fluid passage. Thus, the compressed working fluid passage has an extremely simple structure. As a result, the entire Brayton cycle apparatus is further simplified and downsized.

Preferably, the heat source comes in contact with the case of the scroll expander. The heat source heats the working fluid in the scroll expander through the case of the scroll expander or the fixed expansion scroll fixed to the case.

In this case, the fixed expansion scroll is used to heat the working fluid through heat transfer. As a result, the Brayton cycle apparatus is further simplified and downsized.

The present invention provides an exhaust heat energy recovery apparatus that uses a Brayton cycle apparatus for heating a working fluid fed to an expander by heat transferred from a flow passage wall of an exhaust flow passage of an internal combustion engine.

In this case, the Brayton cycle apparatus is used to heat the working fluid by heat transfer to collect exhaust heat energy of the internal combustion engine. Thus, the apparatus recovers the exhaust heat energy efficiently without increasing the exhaust back pressure of the internal combustion engine.

Further, the exhaust heat energy recovery apparatus heats the working fluid fed to the expander by heat

transferred from the flow passage wall of the exhaust flow passage of the internal combustion engine. As a result, the entire exhaust heat energy recovery apparatus is simplified and downsized.

Preferably, the exhaust heat energy recovery apparatus includes a scroll expander and a heat source for heating the working fluid in the scroll expander through heat transfer. The exhaust of the internal combustion engine is used as the heat source. Thus, the entire exhaust heat energy recovery apparatus is further simplified and downsized.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view showing the structure of a Brayton cycle apparatus according to a first embodiment of the present invention;

Fig. 2 is a diagram showing the appearance of a heat insulation apparatus included in the Brayton cycle apparatus of Fig. 1;

Fig. 3 is a diagram showing the appearance of the heat insulation apparatus of Fig. 2;

Fig. 4 is a plan view showing a compressor case included in the apparatus of Fig. 1;

Fig. 5 is a plan view showing an expander case included in the apparatus of Fig. 1;

Fig. 6 is a perspective view showing the compressor case of Fig. 4;

Fig. 7 is a perspective view showing the expander case of Fig. 5;

Fig. 8 is a diagram showing the structure of an orbital partitioning wall included in the apparatus of Fig. 1;

Fig. 9 is a perspective view showing the orbital

partitioning wall of Fig. 8;

Fig. 10 is a diagram describing an internal structure of a scroll compressor included in the apparatus of Fig. 1;

Fig. 11 is a diagram showing an internal structure of a scroll expander included in the apparatus of Fig. 1;

Fig. 12 is a PV (pressure-volume) diagram of a Brayton cycle of the apparatus of Fig. 1;

Fig. 13 is a diagram showing the positional relationship between a fixed compression scroll and an orbital compression scroll during driving of the Brayton cycle apparatus of Fig. 1;

Fig. 14 is a diagram showing the positional relationship between a fixed expansion scroll and an orbital expansion scroll during driving of the Brayton cycle apparatus of Fig. 1;

Fig. 15 is a schematic diagram showing the structure of a Brayton cycle apparatus and an exhaust heat energy recovery apparatus according to a second embodiment of the present invention;

Fig. 16 is a schematic diagram showing the structure of heat releasing fins of a compressor case included in the apparatus of Fig. 15;

Fig. 17 is a schematic diagram showing the structure of heat absorbing fins of an expander case included in the apparatus of Fig. 15;

Fig. 18 is a schematic diagram showing the structure of a Brayton cycle apparatus according to a third embodiment of the present invention;

Fig. 19 is a diagram showing the appearance of a heat insulation apparatus included in the Brayton cycle apparatus of Fig. 18;

Fig. 20 is a diagram describing the appearance of the heat insulation apparatus of Fig. 19;

Fig. 21 is a plan view showing a compressor case included in the apparatus of Fig. 18;

Fig. 22 is a plan view showing an expander case included in the apparatus of Fig. 18;

Fig. 23 is a perspective view showing the compressor case of Fig. 21;

Fig. 24 is a perspective view showing the expander case of Fig. 22;

Fig. 25 is a perspective view of an orbital partitioning wall included in the apparatus of Fig. 18;

Fig. 26 is a diagram showing the structure of the orbital partitioning wall of Fig. 25;

Fig. 27 is a diagram showing the positional relationship between a fixed compression scroll and an orbital compression scroll during driving of the Brayton cycle apparatus of Fig. 18;

Fig. 28 is a diagram showing the positional relationship between a fixed expansion scroll and an orbital expansion scroll during driving of the Brayton cycle apparatus of Fig. 18;

Fig. 29 is a graph comparing heat energy conversion efficiency between different heating methods used in the apparatus of Fig. 18;

Fig. 30 is a schematic diagram showing the structure of a Brayton cycle apparatus according to a fourth embodiment of the present invention; and

Fig. 31 is a diagram describing the structure of crank mechanisms according to another example of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A first embodiment of the present invention will now be described. Fig. 1 shows a schematic structure of a Brayton cycle apparatus 1. A heat insulation apparatus 2 included in the Brayton cycle apparatus 1 is shown in Figs. 2 and 3. Fig. 2(A) is a front view showing the heat

insulation apparatus 2, Fig. 2(B) is a rear view, Fig. 3(A) is a right side view, and Fig. 3(B) is a left side view of the same.

The heat insulation apparatus 2 includes a scroll compressor 4 and a scroll expander 6. The scroll compressor 4 includes a compressor case 8 shown in the plan view of Fig. 4. A fixed compression scroll 10 is formed in an internal space 9 of the compressor case 8. A compressed working fluid outlet port 9a is arranged in the compressor case 8 at a location corresponding to a central portion of the fixed compression scroll 10. A working fluid inlet port 9b is arranged at peripheral portion of the fixed compression scroll 10. Fig. 6 is a perspective view showing the compressor case 8.

The scroll expander 6 includes an expander case 12 shown in the plan view of Fig. 5. A fixed expansion scroll 14 is formed in an internal space 13 of the expander case 12. A compressed working fluid inlet port 13a is arranged in the expander case 12 at a location corresponding to a central portion of the fixed expansion scroll 14. A working fluid outlet port 13b is arranged at a peripheral portion of the fixed expansion scroll 14. Fig. 7 is a perspective view showing the expander case 12.

A circular orbital recession 8b is arranged inside a contact surface 8a of the compressor case 8. In the same manner, a circular orbital recession 12b is arranged inside a contact surface 12a of the expander case 12. When the contact surfaces 8a and 12a come in contact with each other as shown in Fig. 2, the compressor case 8 is fastened with the expander case 12 by bolts Bt. The two orbital recessions 8b and 12b define an accommodating chamber inside the heat insulation apparatus 2. The accommodating

chamber accommodates an orbital partitioning wall 18. The orbital partitioning wall 18, which is shown in Fig. 8, in the accommodating chamber orbits while sliding in the accommodating chamber or orbits in a narrow gap formed between the orbital partitioning wall 18 and the cases.

An orbital compression scroll 20 is formed to project from a compressor-side surface 18a of the orbital partitioning wall 18 shown in Fig. 8(A). An orbital expansion scroll 22 is formed to project from an expander-side surface 18b of the orbital partitioning wall 18 shown in Fig. 8(B). Fig. 9 is a perspective view of the orbital partitioning wall 18.

Three crank mechanisms 24, each of which is formed in to be disk-shaped are rotatably attached to the peripheral portion of the orbital partitioning wall 18 by crank pins 24b. The three crank mechanisms 24 are respectively accommodated in three crank accommodating units 8c, which are arranged in the compressor case 8. Each crank mechanism 24 has a crankshaft 24a arranged in its central portion. The crankshaft 24a is inserted in a crankshaft reception hole 8d arranged in the center of the crank accommodating unit 8c and is supported on the compressor case 8 in a rotatable manner. With the crank mechanisms 24 being supported on the compressor case 8 in this manner, the entire orbital partitioning wall 18 is supported on the compressor case 8 in a manner enabling orbiting.

In the assembled state for the heat insulation apparatus 2, two of the three crankshafts 24a project outside the heat insulation apparatus 2 as shown in Figs. 1 and 2. The first crankshaft 24a receives a cranking torque when activating the Brayton cycle apparatus 1 from outside the heat insulation apparatus 2. The second crankshaft 24a

outputs a torque generated by the Brayton cycle apparatus 1 out of the heat insulation apparatus 2. The number of crankshafts 24a projecting outside the heat insulation apparatus 2 may be changed from one to two. In this case, the single crankshaft 24a may function to both input the cranking torque and output the generated torque.

The orbital compression scroll 20 arranged on one surface (the compressor-side surface 18a (front surface)) of the orbital partitioning wall 18 with the above-described structure is combined with the fixed compression scroll 10 of the compressor case 8 (Fig. 4 and Fig. 6), and the orbital expansion scroll 22 arranged on the other surface (the expander-side surface 18b (rear surface)) is combined with the fixed expansion scroll 14 of the expander case 12 (Fig. 5 and Fig. 7). The compressor case 8, the expander case 12, and the orbital partitioning wall 18 are then fastened together by the bolts Bt to form the heat insulation apparatus 2.

Fig. 10 shows the internal structure of the scroll compressor 4 included in the heat insulation apparatus 2 with this structure. Fig. 10 shows the orbital compression scroll 20 arranged on the compressor-side surface 18a (front surface) of the orbital partitioning wall 18 and the compressor case 8 that is combined with the orbital compression scroll 20. When the scroll compressor 4 is arranged so that the compressor case 8 (the orbital compression scroll 20) is located at the upper side and the expander case 12 (the orbital expansion scroll 22) is located at the lower side, the part of the compressor case 8 located above the orbital partitioning wall 18 is indicated by single-dashed lines. The orbital compression scroll 20 is shown in black.

Fig. 11 shows the internal structure of the scroll expander 6 included in the heat insulation apparatus 2. Fig. 11 shows the orbital expansion scroll 22 arranged on the expander-side surface 18b (rear surface) of the orbital partitioning wall 18 and the expander case 12 that is combined with the orbital expansion scroll 22 as viewed through the orbital partitioning wall 18 from the side of the scroll compressor 4. The parts of the fixed expansion scroll 14 and the orbital expansion scroll 22 located below the orbital partitioning wall 18 are indicated by broken lines.

Referring to Figs. 10 and 11, the crankshafts 24a rotate clockwise as viewed in the drawings from the side of the compressor case 8 so that the orbital partitioning wall 18 orbits clockwise. As a result, the scroll compressor 4 realizes a heat-insulation compression stroke in the PV (pressure-volume) diagram of a Brayton cycle of Fig. 12 and the scroll expander 6 realizes a heat-insulation expansion stroke in the PV diagram.

The orbital state will now be described with reference to Fig. 13 and Fig. 14. Fig. 13 shows the orbital partitioning wall 18 viewed from the side of the compressor case 8 and the part of the compressor case 8 located above the orbital partitioning wall 18 in an overlapped state to show the positional relationship between the fixed compression scroll 10 and the orbital compression scroll 20. In the same manner, Fig. 14 shows the orbital partitioning wall 18 viewed from the side of the compressor case 8 and the part of the expander case 12 located below the orbital partitioning wall 18 in an overlapped manner to show the positional relationship between the fixed expansion scroll 14 and the orbital expansion scroll 22. The orbital compression scroll 20 and the orbital expansion

scroll 22, which are positioned on the front and rear surfaces of the orbital partitioning wall 18 produces the same orbiting action. Thus, the orbiting shown in Fig. 13 and the orbiting shown in Fig. 14 occur simultaneously at the front and rear surfaces of the orbital partitioning wall 18.

The orbital partitioning wall 18 orbits clockwise as viewed from the side of the scroll compressor 4 as described above. Thus, the position of the orbital compression scroll 20 with respect to the fixed compression scroll 10 changes sequentially from the states (1) to (8) shown in Fig. 13. As a result, an initial volume Va1 of a working fluid (atmospheric gas in this case) is introduced into the internal space 9 of the compressor case 8 through the working fluid inlet port 9b, and the working fluid flows toward the center of the compressor case 8 while gradually reducing its volume. When the volume of the working fluid reaches a final volume Va2 (Va1 > Va1) at the central portion of the compressor case 8, the compressed working fluid outlet port 9a opens so that the compressed working fluid is fed from the compressed working fluid outlet port 9a to the heating device 30 (Fig. 1).

During the orbiting of the orbital compression scroll 20, orbiting simultaneously occurs in the scroll expander 6. The position of the orbital expansion scroll 22 with respect to the fixed expansion scroll 14 changes sequentially from the states (1) to (8) shown in Fig. 14. As a result, an initial volume Vb2 of the working fluid heated in the heating device 30 is introduced from the compressed working fluid inlet port 13a into the internal space 13 of the expander case 12, and flows toward the peripheral side of the expander case 12 while gradually increasing its volume. When the volume of the working fluid

reaches a final volume Vb1 (Vb1 > Vb2) at the peripheral portion of the expander case 12, the working fluid is released from restriction imposed by the fixed expansion scroll 14 and the orbital expansion scroll 22, and is discharged outside the expander case 12 from the working fluid outlet port 13b.

The dimensions of the fixed expansion scroll 14 and the orbital expansion scroll 22 in the axial direction are greater than the dimensions of the fixed compression scroll 10 and the orbital compression scroll 20 in the axial direction, and the scrolls are designed to satisfy the relationship Va1 < Vb1 and Va2 < Vb2.

The heat insulation apparatus 2 and the heating device 30 with the above-described structures are combined together to complete the Brayton cycle apparatus 1 shown in Fig. 1. The heating device 30 uses a double pipe and includes a heat source flow passage 30a, which functions as an inner passage, and an outer passage 30b, which is arranged to surround the flow passage 30a. The heating device 30 has the working fluid flow through the outer passage 30b. The working fluid flowing through the outer passage 30b exchanges heat with fluid flowing through the heat source flow passage 30a through the pipe wall (flow passage wall) of the heat source flow passage 30a. When an exhaust pipe of an internal combustion engine is used as the heat source flow passage 30a, exhaust heat energy of the internal combustion engine is recovered. In this case, the exhaust flows through the heat source flow passage 30a and the heat of the exhaust is transferred to the working fluid (air) flowing through the outer passage 30b.

The values of the volumes Va1, Va2, Vb1, and Vb2 above are designed to maximize the heat conversion

efficiency of the Brayton cycle apparatus 1 by considering the working fluid temperature at the working fluid inlet port 9b, the heat exchanger efficiency in the heating device 30, the working fluid temperature at the compressed working fluid inlet port 13a, and the heat insulation efficiency in the scroll compressor 4 and the scroll expander 6.

The first embodiment has the advantages described below.

(1) Unlike the gas turbine Brayton cycle apparatus of the prior art, the Brayton cycle apparatus 1 of the preferred embodiment uses the scroll compressor 4 and the scroll expander 6. This simplifies and downsizes the structure.

In particular, in the heat insulation apparatus 2, the working fluid is moved, compressed, and expanded inside the scroll compressor 4 and the scroll expander 6 in spaces partitioned and sealed by the combination of the fixed scrolls 10 and 14 and the orbital scrolls 20 and 22. Thus, the efficiency in conversion from heat energy to kinetic energy is high.

The external energy source is only required to transfer heat to the working fluid via the pipe wall of the flow passage 30a and exchange heat with the working fluid. This downsizes the external energy source. Further, the pressure of the energy source itself causes no problem, and the back pressure of the energy source including the exhaust is unaffected.

As a result, the Brayton cycle apparatus 1 of the present embodiment converts heat energy to kinetic energy

efficiently without increasing the back pressure of the energy source. Thus, when the Brayton cycle apparatus 1 of the present embodiment is applied to an internal combustion engine, the apparatus recovers the exhaust heat energy efficiently without increasing the exhaust back pressure of the internal combustion engine.

(2) The orbital compression scroll 20 of the scroll compressor 4 and the orbital expansion scroll 22 of the scroll expander 6 are respectively arranged at opposite sides of the orbital partitioning wall 18, which is orbited by the crankshafts 24a. The compressor case 8, in which the fixed compression scroll 10 is formed, is set on the orbital compression scroll 20 side of the orbital partitioning wall 18 to come in contact with the orbital partitioning wall 18 in a slidable manner or to face the orbital partitioning wall 18 with a narrow gap therebetween. The orbital compression scroll 20 and the fixed compression scroll 10 are combined to form the scroll compressor 4. The expander case 12, in which the fixed expansion scroll 14 is formed, is set on the orbital expansion scroll 22 side of the orbital partitioning wall 18 to come in contact with the orbital partitioning wall 18 in a slidable manner or to face the orbital partitioning wall 18 with a narrow gap therebetween. The orbital expansion scroll 22 and the fixed expansion scroll 14 are combined to form the scroll expander 6.

The scroll compressor 4 and the scroll expander 6 are formed in this manner so that the Brayton cycle apparatus 1 is further simplified and downsized.

(3) As described above, the orbital partitioning wall 18 covers the expander case 12. Thus, the orbital partitioning wall 18 is exposed to the high-temperature

working fluid that is introduced into the scroll expander 6. However, the compressor case 8 is enabled to contact the orbital partitioning wall 18 from the side opposite to the expander case 12. As a result, heat transferred from the scroll expander 6 to the orbital partitioning wall 18 is removed by the compressor case 8 and released into the atmosphere.

The heat releasing effect of the compressor case 8 prevents the orbital partitioning wall 18 from being heated to a high temperature. As a result, the orbital partitioning wall 18 is prevented from being deformed by heat, and the dimensional accuracy of the orbital partitioning wall 18 is maintained. This prevents the working fluid from leaking from the heat insulation apparatus 2 and prevents the friction coefficient during orbiting of the orbital partitioning wall 18 from becoming large. As a result, high energy conversion efficiency is maintained.

Thus, the orbital partitioning wall 18 and the scroll compressor 4 in particular may be made of a light alloy with a low heat resistance. This contributes to further decreasing the weight of the Brayton cycle apparatus 1.

(4) The scroll compressor 4 uses the atmospheric gas (air) drawn through the working fluid inlet port 9b as the working fluid, and the scroll expander 6 releases the expanded working fluid from the working fluid outlet port 13b into the atmosphere. In this manner, the atmospheric gas is used as the working fluid. This eliminates the need for an apparatus for releasing heat of the working fluid and further simplifies and downsizes the structure of the Brayton cycle apparatus 1.

A second embodiment of the present invention will now be described. In the present embodiment, a Brayton cycle apparatus 51 with the structure shown in Fig. 15 is used to collect exhaust heat energy of an internal combustion engine Eng that is mounted on a vehicle. A heat insulation apparatus 52 is formed by a scroll compressor 54 and a scroll expander 56. The internal structures of the scroll compressor 54 and the scroll expander 56 are the same as the structures of the scroll compressor 4 and the scroll expander 6 described in the first embodiment.

The present embodiment differs from the first embodiment in the following points. More specifically, a large number of heat releasing fins 58b, which are formed as projections, are arranged on an end surface 58a of a compressor case 58 as shown in Fig 15 and Fig. 16. The heat releasing fins 58b are used to discharge from the compressor case 58 heat, which is transferred from the internal orbital partitioning wall 18 to the compressor case 58. More specifically, the heat releasing fins 58b improve the releasing efficiency of the heat received from the high-temperature scroll expander 56 by the orbital partitioning wall 18 through the compressor case 58.

Further, a large number of heat absorbing fins 62b, which are formed as projections, are also arranged on an end surface 62a of an expander case 62 as shown in Fig 15 and Fig. 17. A cover 62c is arranged on the end surface 62a of the expander case 62. The cover 62c covers a compressed working fluid inlet port 63a and the heat absorbing fins 62b to define a heat absorption chamber 62d. The working fluid heated by a heating device 80 is introduced into the heat absorption chamber 62d. Thus, the working fluid introduced into the heat absorption chamber 62d heats the heat absorbing fins 62b. The compressed working fluid inlet

port 63a that opens into the heat absorption chamber 62d absorbs the heated working fluid. The working fluid introduced into the heat absorption chamber 62d heats the working fluid inside the expander case 62 through the end surface 62a of the wall of the heat absorption chamber 62d. Thus, a pressure decrease caused by expansion of the working fluid in the scroll expander 56 is small. As a result, even when the expansion coefficient of the scroll expander 56 is high, the working fluid can be set in an atmospheric pressure state and discharged from the working fluid outlet port 63b. This enables the Brayton cycle apparatus 51 to collect the exhaust heat energy more efficiently.

The heating device 80 includes two passages, namely, a passage 80c for having the working fluid pass through the entire length of a double pipe 80b and a passage 80d for having the working fluid pass through only part of the double pipe 80b. The passage distribution state of the compressed working fluid supplied from the scroll compressor 54 is adjustable using a distribution valve 80e. The distribution ratio of the passages 80c and 80d in the present embodiment is adjusted in a manner that the working fluid supplying temperature detected by a temperature sensor 81 arranged at an opening of the compressed working fluid inlet port 63a becomes equal to a predetermined reference temperature. More specifically, the distribution ratio of the distribution valve 80e is adjusted in a manner that the temperature of the working fluid becomes equal to a reference temperature that is appropriate for starting expansion in the scroll expander 56 when the working fluid reaches the compressed working fluid inlet port 63a after heat is absorbed by the heat absorbing fins 62b.

Crankshafts 74a of the Brayton cycle apparatus 51 are

rotated when the internal combustion engine Eng starts driving the Brayton cycle apparatus 51. However, after the driving of the Brayton cycle apparatus 51 starts, the crankshafts 74a rotate independently of the output of the internal combustion engine Eng by using heat energy of the exhaust that passes through the heating device 80. Thus, the crankshafts 74a need to be disconnected from the internal combustion engine Eng. For this purpose, an electromagnetic clutch 92 is arranged between an output shaft 64 of the internal combustion engine Eng and the crankshafts 74a of the Brayton cycle apparatus 51.

The distribution ratio control of the distribution valve 80e and the engagement/disengagement control of the electromagnetic clutch 92 are executed by an electronic control unit (ECU) 94 based on the driving state of the internal combustion engine Eng.

For example, the electromagnetic clutch 92 is set in a disengaged state before the internal combustion engine Eng is started. At the timing when the internal combustion engine exhaust temperature reaches a sufficiently high temperature after the internal combustion engine Eng is started, the electromagnetic clutch 92 is engaged so that the crankshafts 74a of the Brayton cycle apparatus 51 are rotated based on an output of the internal combustion engine Eng. The ECU 94 drives a valve actuator 80f and adjusts the distribution valve 80e in a manner that the working fluid temperature detected by the temperature sensor 81 is adjusted to, for example, 350°C.

Afterwards, the ECU 94 disengages the electromagnetic clutch 92. As a result, the crankshafts 74a of the Brayton cycle apparatus 51 rotate independently to rotate an apparatus for recovering the exhaust heat energy, or a

generator 96 in this case. As a result, the exhaust heat energy is recovered as electric energy and used as a vehicle power supply or stored in a battery.

With the above-described structure, the expander case 62, which directly comes in contact with the high-temperature working fluid, is made of a heat-resistant material (e.g. an iron alloy such as cast iron). The compressor case 58, through which the working fluid flows with a relatively low temperature, is made of a high heat-conductive material (particularly a light alloy such as an aluminum alloy). The orbital partitioning wall 18 is made of a high heat-conductive material so that the orbital partitioning wall 18 is cooled by transferring heat to the compressor case 58.

The second embodiment described above has the advantages described below.

(1) The heat releasing fins 58b are formed on the compressor case 58. Thus, the compressor case 58 can easily release heat into the atmosphere. This strengthens advantage (3) described in the first embodiment.

(2) The cover 62c covers the end surface 62a of the expander case 62 and defines the heat absorption chamber 62d. As described above, the working fluid expanded in the scroll expander 56 is heated by the wall of the expander case 62 having the end surface 62a. Further, the heat absorbing fins 62b are formed on the end surface 62a. The heat absorbing fins 62b enhance heat conductivity of the end surface 62a, and enable the Brayton cycle apparatus 51 to convert heat energy to kinetic energy further efficiently without complicating the structure of the Brayton cycle apparatus 51.

(3) The exhaust pipe is formed by the double pipe 80b. The heating device 80 is formed as a heat exchanger for exchanging heat between the high-temperature gas (the exhaust of the internal combustion engine Eng in this case) and the working fluid. The Brayton cycle apparatus 51 recovers the exhaust heat energy as kinetic energy. Thus, the Brayton cycle apparatus 51 converts the exhaust heat energy to kinetic energy more efficiently without increasing the exhaust back pressure of the internal combustion engine Eng.

(4) A light alloy may be used as a material for the compressor case 58 and the orbital partitioning wall 18 as described above. This reduces the weight of the entire Brayton cycle apparatus 51. When the Brayton cycle apparatus 51 is applied to an internal combustion engine that is mounted on a vehicle, the Brayton cycle apparatus 51 improves fuel efficiency of the engine.

(5) Advantages (1), (2), and (4) of the first embodiment are obtained.

A third embodiment of the present invention will now be described. Fig. 18 is a schematic diagram showing the structure of a Brayton cycle apparatus 101. A heat insulation apparatus 102 included in the Brayton cycle apparatus 101 is shown in Figs. 19 and 20. Fig. 19(A) is a front view showing the heat insulation apparatus 102, Fig. 19(B) is a rear view, Fig. 20(A) is a right side view, and Fig. 20(B) is a left side view of the same.

In the same manner as the first embodiment, a working fluid inlet port 109b projects from a peripheral portion of a scroll compressor 104 and a working fluid outlet port

113b projects from a peripheral portion of a scroll expander 106.

Unlike the first embodiment, a compressed working fluid outlet port 9a is not arranged in a compressor case 108 and a compressed working fluid inlet port 13a is not arranged in an expander case 112 as shown in Figs. 21 to 24. Fig. 21 is a plan view showing the compressor case 108, Fig. 22 is a plan view showing the expander case 112, Fig. 23 is a perspective view showing the compressor case 108, and Fig. 24 is a perspective view showing the expander case 112.

Instead of the compressed working fluid outlet port 9a and the compressed working fluid inlet port 13a, a through-hole 118c is formed in a central portion of an orbital partitioning wall 118 as shown in Figs. 25 and 26. Fig. 25 is a perspective view showing the orbital partitioning wall 118, Fig. 26(A) is a plan view of the orbital partitioning wall 118 showing a compressor-side surface 118a of the orbital partitioning wall 118, and Fig. 26(B) is a rear view of the orbital partitioning wall 118 showing an expander-side surface 118b of the orbital partitioning wall 118.

In the scroll compressor 104, the orbital partitioning wall 118 orbits as shown in the states (1) to (8) in Fig. 27. An orbital compression scroll 120 of the orbital partitioning wall 118 moves relative to a fixed compression scroll 110 of the compressor case 108 so that the working fluid introduced from the working fluid inlet port 109b into the scroll compressor 104 is compressed and reaches the through-hole 118c formed in the central portion of the orbital partitioning wall 118. Fig. 27 shows the orbital partitioning wall 118 viewed from the side of the

compressor case 108 and the compressor case 108 located above the orbital partitioning wall 118 in an overlapped manner to describe the positional relationship between the fixed compression scroll 110 and the orbital compression scroll 120. Accordingly, the left and right sides shown in Fig. 27 are reversed from the state shown in Fig. 21.

The working fluid in a compressed state passes through the through-hole 118c so that the working fluid is immediately introduced into the scroll expander 106 from the scroll compressor 104 as indicated by a broken line Ap in Fig. 18.

In the scroll expander 106, the orbital partitioning wall 118 orbits as shown in (1) to (8) in Fig. 28. An orbital expansion scroll 122 of the orbital partitioning wall 118 moves relative to a fixed expansion scroll 114 of the expander case 112 so that the working fluid introduced through the through-hole 118c into the scroll expander 106 expands and reaches the working fluid outlet port 113b.

Fig. 28 shows the orbital partitioning wall 118 viewed from the side of the compressor case 108 and the part of the expander case 112 located below the orbital partitioning wall 118 in an overlapped manner to show the positional relationship between the fixed expansion scroll 114 and the orbital expansion scroll 122.

The expander case 112 comes in contact with or is joined with a flow passage 130a (Fig. 18) as a heat source. The expander case 112 exchanges heat with a fluid flowing through the flow passage 130a through a pipe wall (flow passage wall) of the flow passage 130a. Thus, the working fluid expands while being heated by the heat transferred to the working fluid that comes in contact with the expander

case 112 or the fixed expansion scroll 114.

The orbital partitioning wall 118 with this structure orbits clockwise in Fig. 27 and 28 to realize a heat-insulation compression stroke, an isobaric heating stroke, and a heat-insulation expansion stroke in the PV diagram of the Brayton cycle shown in Fig. 12.

In the above-described structure, the expander case 112 comes in contact with the high-temperature flow passage 130a and is heated to a high temperature by the heat transfer from the flow passage 130a. As a result, the working fluid is heated by the expander case 112 and the fixed expansion scroll 114. Thus, the expander case 112 and the fixed expansion scroll 114 are made of a heat-resistant material (e.g. an iron alloy such as cast iron). The expander case 112 and the fixed expansion scroll 114 may be made of a light alloy such as an aluminum alloy. Because the temperature of the working fluid in the compressor case 108 is relatively low, the compressor case 108 is made of a high heat-conductive material (particularly a light alloy such as an aluminum alloy). The orbital partitioning wall 118 is made of a high heat-conductive material so that the orbital partitioning wall 18 may be cooled by transferring heat to the compressor case 58.

With the above-described structure, heat energy transferred from the flow passage 130a to the expander case 112 is converted to rotation energy of crankshafts 124a.

Fig. 29 shows a graph comparing the heat energy conversion efficiency experiments in the present embodiment case, in which the expander case 112 is heated, with the heat energy conversion efficiency experiments in the first embodiment case, in which the expander case 112 is not

heated and the working fluid is introduced into the scroll expander 106 after the working fluid is heated separately. To correctly indicate the difference in the torque gain in the scroll expander 106 between the different heating methods, this graph compares the output torque of the crankshafts 124a when the expander case 112 is heated with an output torque of the crankshafts 124a when the working fluid introduced into the expander case 112 is heated in the state in which the scroll expander 106 is disconnected from the Brayton cycle apparatus 101. The horizontal axis of the graph indicates a temperate increase difference ΔT, which is the difference between a temperature increase of the expander case 112 and a temperature increase of the working fluid occurring via heating. The vertical axis of the graph indicates a torque gain (Nm).

As shown in the graph, the heat energy conversion efficiency is higher when the expander case 112 made of an aluminum alloy is heated than when the working fluid is heated. When the expander case 112 is made of cast iron, clearance for the mechanism of the scroll expander 106 may be reduced and the heat energy conversion efficiency is further increased.

The third embodiment has the advantages described below.

(1) Advantages (1) to (4) of the first embodiment are obtained.

(2) The Brayton cycle apparatus 101 of the present embodiment heats the working fluid in the scroll expander 106 using the heat transferred from the heat source (the flow passage 130a) without using a heating device for separately heating the working fluid.

Thus, the compressed working fluid passage has a simple structure. The compressed working fluid passage is actually realized by the through-hole 118c formed in the orbital partitioning wall 118.

Further, the expander case 112 and the fixed expansion scroll 114, which are the components of the scroll expander 106, are used to transfer heat to the working fluid and heat the working fluid. As a result, the Brayton cycle apparatus 101 is further simplified and downsized.

A fourth embodiment of the present invention will now be described. As shown in Fig. 30, a Brayton cycle apparatus 201 of the present embodiment differs from the structure of the first embodiment shown in Fig. 1 in that a heat insulator 201a is arranged to cover the expander case 12 in the heat insulation apparatus 2 and keep the expander case 12 warm. The other parts of the Brayton cycle apparatus 201 are the same as the structure in the first embodiment. Thus, the components of the Brayton cycle apparatus 201 that are the same as the components in the first embodiment are denoted by the same reference numerals.

The fourth embodiment has the advantages described below.

(1) Advantages (1) to (4) of the first embodiment are obtained.

(2) The heat insulator 201a keeps the wall surface of the expander case 12 warm. This prevents heat from being released from the expander case 12 outside through heat

transfer from the expander case 12 when the working fluid is expanded in the scroll expander 6 in a heat-insulated state.

In this manner, the wall surface of the expander case 12 is kept warm to prevent heat energy from leaking from the scroll expander 6. As a result, the heat energy is converted to kinetic energy more efficiently.

The above embodiments may be modified in the following forms.

(a) The Brayton cycle apparatus shown in Fig. 1, Fig. 18, or Fig. 30 may be used as an exhaust heat energy recovery apparatus for an internal combustion engine instead of the Brayton cycle apparatus used in the second embodiment.

In the above embodiments, the Brayton cycle apparatus used to collect exhaust heat energy from an internal combustion engine uses the scroll compressor and the scroll expander. Another compressor, such as a screw compressor, a vane compressor, or a turbo compressor, may be used instead of the scroll compressor. A turbine compressor may be used instead of the scroll expander.

A positive-displacement compressor and a positive-displacement expander may be used instead of the scroll compressor and the scroll expander. The Brayton cycle apparatus may be formed by combining a positive-displacement compressor for compressing a working fluid and a scroll expander. In this case, the scroll expander may operate in cooperation with the operation of the positive-displacement compressor.

(b) The orbital partitioning wall 18 is supported by the three crank mechanisms 24 as shown in Fig. 8. However, the present invention should not be limited to this structure. The orbital partitioning wall 18 may be supported by two crank mechanisms 24 or may be supported by four or more crank mechanisms 24. Although each crank mechanism 24 is circular, each crank mechanism 24 may include a balancer 100 as shown in Fig. 31 to improve the vibration reducing effect during driving of the Brayton cycle apparatus. The same applies to the orbital partitioning wall 118 in the third embodiment.

(c) Although the heat releasing fins 58b and the heat absorbing fins 62b are formed as projections as shown in Figs. 16 and 17, the heat releasing fins 58b and the heat absorbing fins 62b may be formed as flat plates or bent plates.

(d) The heat releasing fins 58b shown in Figs. 15 and 16 may be arranged on the compressor case 108 in the third embodiment. This structure enables the heat of the compressor case 108 to be easily released into the atmosphere and strengthens advantage (3) described in the first embodiment.

In the third embodiment, the expander case 112 comes in contact with or joined together with the flow passage 130a, which functions as a heat source, as shown in Fig. 18 to exchange heat through the pipe wall (flow passage wall) of the flow passage 130a. However, the expander case 112 may be formed to have a flow passage through which the exhaust flows, and the exhaust may be guided to this flow passage.

In the third embodiment, a peripheral portion of the

expander case 112 excluding parts that are in contact with or joined with the flow passage 130a may be covered by a heat insulator to keep the expander case 112 warm.

(e) In the above embodiments, the working fluid inlet port and the working fluid outlet port are open to the atmosphere and the atmospheric gas is used as the working fluid. However, the passage of the working fluid may be closed, and a gas other than the atmospheric gas may be used as the working fluid. In this case, it is preferable that a heat releasing apparatus be arranged.

(f) In the above embodiments, the orbital compression scroll and the orbital expansion scroll are formed to sandwich the orbital partitioning wall to operate the expander in cooperation with movement of the compressor. The synchronous movement intends to mean that the compressor is linked to the expander in a manner that the compressor and the expander move in a unified manner. Thus, operating the expander in cooperation with the movement of the compressor is equivalent to operating the compressor in cooperation with the operation of the expander. Unlike the above embodiments, this compressor does not have to be directly connected to the expander. Particularly in the first, second, and fourth embodiments, a shaft or a gear may be arranged between the compressor and the expander to operate the expander in cooperation with the operation of the compressor.